Nutritional and Structural Characterization of Dietary Fibre Concentrates from sustainable Agro-Industrial By-Products

Shailesh Kumar[1], Sunita Mishra[2], Priyanka Shankar[3]

Research Scholar[1], Professor[2], Assistant Professor[3]
Department of Food and Nutrition, Babasaheb Bhimrao Ambedkar University, Vidya Vihar, Raebareli Road, Lucknow - 226025
Uttar Pradesh, India
***Corresponding email**- shaileshkphd@gmail.com

Abstract

The escalating generation of by-products from fruit and vegetable processing has become a major sustainability challenge, encouraging Valorization strategies that transform these un-utilized biomass resources into functional ingredients with enhanced nutritional and economic value. This study aimed to develop dietary fibre concentrates (DFCs) from mango and potato peels and evaluate their nutritional, and structural characteristics. Mango and potato peels were processed into dietary fibre concentrates through drying, grinding, and sieving. Proximate analysis revealed that the dietary fibre concentrates (DFCs) were rich in dietary fibre and contained substantial amounts of ash and carbohydrates, indicating their nutritional significance and potential application in functional food formulations. Structural characterization using scanning electron microscopy (SEM) demonstrated irregular, porous, and fibrous surface morphology, which contributes to improved water and oil-holding capacities. Energy dispersive spectroscopy (EDS) confirmed the presence of essential elements such as carbon and oxygen, supporting the organic nature of the fibre matrix. X-ray diffraction (XRD) analysis indicated a semi-crystalline structure characteristic of cellulose and hemicellulose components. Fourier transform infrared spectroscopy (FTIR) identified functional groups corresponding to polysaccharides, lignin, and cellulose, confirming the complex fibre composition. The findings demonstrate that peel-derived DFCs possess valuable nutritional and functional attributes, making them suitable for incorporation into functional food products. This study highlights the potential of fruit and vegetable processing by-products as sustainable sources of dietary fibre and supports their utilization in value-added food applications.

Keywords
Dietary fibre concentrate, Mango peel, Potato peel, Proximate analysis, Agro-waste valorization, Functional food.

Graphical Abstract

1. Introduction

According to **Mirabella et al. (2013),** the expansion of the food processing sector has led to a considerable rise in the generation of agro-industrial waste, raising substantial environmental and economic problems. Mango (Mangifera indica) and potato (Solanum tuberosum) processing produces large volumes of peel waste, which has high concentrations of dietary fibre, polyphenols, and other bioactive substances that might be used in food and nutraceutical products **(Ajila et al., 2009).** The conversion of agro-industrial by-products into functional food components has become a viable strategy to improve sustainability and resource use. The well-established physiological advantages of dietary fibre, which include improving digestive health, regulating postprandial glucose levels, and reducing the prevalence of chronic illnesses, provide credence to this approach **(Anderson et al., 2009).** As a result, research into fiber-rich agricultural leftovers as useful components for functional food applications is growing **(Elleuch et al., 2010).** Nevertheless, the majority of current research focuses on compositional profile and provides little information about the structural and physicochemical characteristics that control techno-functional performance. Predicting ingredient behaviour in complex food matrices requires an understanding of features including crystallinity, surface morphology, and functional group distribution **(Wang et al., 2013).** In order to produce dietary fibre concentrates from mango and potato peels, this work integrates compositional, antioxidant, and advanced structural characterisation utilising FTIR, SEM, EDS, and XRD **(Ballester Sanchez et al., 2019).** By offering a unique, comprehensive structure function assessment of dietary fibres extracted from peels, this study closes the gap between functional application in food systems and compositional analysis. This strategy promotes the creation of health-promoting ingredients in line with the principles of the circular bioeconomy and supports sustainable waste valorisation **(Galanakis, 2012).**

Waste valorisation is strongly related to the circular bioeconomy's tenets, which encourage the conversion of biological waste streams into products with economic value. Fruit and vegetable processing residues are increasingly acknowledged as sources of dietary fibre, phenolic compounds, antioxidants, vitamins, minerals, and other bioactive components rather than as low-value trash **(Galanakis, 2012).** In addition to increasing sustainability, the recovery and use of these chemicals opens up possibilities for the development of functional food additives that can raise the nutritional value of food items. The consumption of bioactive-rich compounds made from agricultural by-products has attracted significant scientific and commercial attention as consumer demand for clean-label, health-promoting, and ecologically sustainable foods continues to rise **(Lesmana et al., 2021)**. Due to its proven physiological and technical advantages, dietary fibre has drawn special attention among the many bioactive elements found in agro-industrial wastes. The term "dietary fibre" refers to a broad category of plant compounds and non-digestible carbohydrates that are difficult for the human digestive system to break down. Dietary fibre is often divided into two categories based on its solubility: soluble dietary fibre (SDF) and insoluble dietary fibre (IDF). Total dietary fibre (TDF) is the sum of these fractions. Soluble and insoluble fibres both support human health via various physiological processes. Soluble fibre is associated with improved glycaemic control, cholesterol reduction, and modulation of gut microbiota, whereas insoluble fibre promotes intestinal transit, bowel regularity, and digestive health. Numerous epidemiological and clinical studies have demonstrated that increased dietary

fibre consumption is associated with a reduced risk of obesity, cardiovascular disease, type 2 diabetes, and certain gastrointestinal disorders **(Anderson et al., 2009)**.

Dietary fibres have significant nutritional value as well as significant techno-functional characteristics that affect food quality and processing efficiency. The physicochemical and structural features of fibre materials have a major role in determining functional qualities such water-holding capacity, oil-holding capacity, swelling capacity, hydration behaviour, viscosity, and adsorption capabilities **(Fayaz et al., 2023).** These characteristics are crucial in defining food items' texture, mouthfeel, moisture retention, emulsion stability, and shelf life. For use in baked goods, drinks, meat substitutes, dairy substitutes, nutraceutical formulations, and other functional foods, fiber-rich substances made from plant by-products have therefore grown in appeal **(Lesmana et al., 2021).** The manufacture of juice, pulp, nectar, and dried fruit from mangos (Mangifera indica L.), one of the most popular tropical fruits in the world, produces significant amounts of processing waste. Despite being rich in nutritional fibre, phenolic compounds, carotenoids, pectin, and antioxidant elements, mango peel makes up a significant amount of the fruit mass and is frequently thrown away **(Ismail et al., 2024)**. Mango peel's high cellulose, hemicellulose, and lignin content has been shown in earlier research to contribute to its fiber-rich composition and functional potential. Mango peel is a desirable raw material for the creation of health-promoting food ingredients because it contains both bound and free phenolic chemicals, which increase its antioxidant activity.

In **2009, Ajila et al.** Similar amounts of peel waste are produced during the processing of potatoes (Solanum tuberosum L.), especially when chips, fries, starch, and dried potato products are made. Dietary fibre, resistant starch, minerals, phenolic compounds, and other phytochemicals are among the beneficial elements found in potato peels that are underutilised despite their nutritional value **(Lesmana et al., 2021).** Potato peels' cell walls are made up of cellulose, hemicellulose, pectin, and lignin, all of which support the peels' structural integrity and useful qualities. Therefore, recovering dietary fibre from potato peel waste is a practical way to lessen the impact on the environment while also producing nutritious ingredients that can be used in meals. The molecular makeup and structural structure of dietary fibre components have a significant impact on their functioning. Cellulose microfibrils embedded in a network of hemicellulose, lignin, and pectin make up the lignocellulosic matrix of plant-derived fibres. Hydration characteristics, adsorption behaviour, fermentability, and ingredient performance in food systems can all be greatly impacted by changes in crystallinity, particle morphology, pore structure, and functional group distribution **(Tejada-Ortigoza et al., 2017).** Therefore, forecasting the behaviour of dietary fibre concentrates throughout processing and end use applications requires an understanding of their structural properties.

Advanced analytical methods offer insightful information on the structure-function relationships of dietary fibre components. Surface morphology, particle arrangement, and porosity all of which are strongly associated with hydration and adsorption properties can be seen using scanning electron microscopy (SEM). EDS, or energy dispersive X-ray spectroscopy, can provide details about the distribution of minerals and elemental composition in the fibre matrix **(Zhao et al., 2017).** While X-ray diffraction (XRD) analysis reveals the crystalline and amorphous organization of polysaccharide structures, Fourier Transform Infrared Spectroscopy (FTIR) makes it easier to identify functional groups linked to cellulose, hemicellulose, lignin, and pectin **(Ballester-Sánchez et al., 2019).** When taken as a whole, these methods help to provide a thorough knowledge of the physicochemical characteristics controlling the functioning of dietary fibre components. While many studies have looked at the nutritional makeup of fruit and vegetable by-products,

the majority of the research that is now accessible concentrates on proximate composition and dietary fibre measurement. Comparatively few investigations have shown connections between chemical composition, microstructure, and functional performance by combining compositional analysis with thorough structural characterisation **(Dhingra et al., 2011).** Moreover, nothing is known about the structural characteristics and usefulness of dietary fibre concentrates made from potato and mango peels in a single analytical framework. The efficient use of these materials in cutting-edge culinary applications is limited by this knowledge gap. In order to create dietary fibre concentrates from mango and potato peels and to thoroughly assess their nutritional and structural qualities, the current study was conducted **(Soni et al., 2025).** Using SEM, EDS, FTIR, and XRD studies, the study combines proximate composition, total phenolic content, and advanced structural characterisation to give a comprehensive evaluation of dietary fibres obtained from peels **(Nawirska & Kwaśniewska, 2004).** This study advances knowledge of the functional potential of agro-industrial by-products by demonstrating connections between composition and structural characteristics. The results offer scientific proof for the use of fruit and vegetable processing leftovers as value-added functional ingredients in circular bioeconomy and sustainable food production systems. They also assist the sustainable valorisation of these residues **(Eva et al., 2025).**

2. Materials and Methods

2.1 Collection of Raw Materials

Fresh mango (Mangifera indica L.) and potato (Solanum tuberosum L.) peels were procured from local markets. Healthy, non-infected, and undamaged samples were selected, while green and sprouted potatoes were excluded to minimize glycoalkaloid content. The peels were manually sorted, washed thoroughly under potable water, and prepared following standard hygienic practices.

To improve safety and reduce anti-nutritional compounds, mango peels were soaked in 2% salt solution for 10 min, rinsed with distilled water, and blanched at 90°C for 3 min followed by immediate cooling in ice water. Potato peels were blanched at 90-95°C for 2-5min to reduce glycoalkaloids such as solanine and chaconine. All pre-treatment procedures were carried out according to AOAC guidelines (AOAC, 2019).

Table 1: Standard Blanching Drying Conditions

Material	Blanching Temperature (°C)	Blanching Time (min)	Cooling Condition	Drying Temperature (°C)	Drying Time (h)
Mango Peel	90 ± 2	3	Ice water (0–4°C) for 3 min	55 ± 2	14
Potato Peel	90 ± 2	3	Ice water (0–4°C) for 3 min	55 ± 2	14

Note: Blanching was performed to reduce enzymatic activity, microbial load, allergenic compounds (urushiol in mango peel), and glycoalkaloids (solanine and chaconine in potato peel). Dried peels were subsequently ground and sieved to obtain dietary fibre concentrates (DFCs)

2.2 Preparation of Dietary Fibre Concentrate

After being cleaned and blanched, fresh peels from potatoes (Solanum tuberosum L.) and mangos (Mangifera indica L.) were dried in a tray drier until they reached a consistent weight. Potato peels were dried at 55-60°C for 12-14 hours, and mango peels were dried at 50-55°C for 14-16 hours. To achieve a consistent particle size, the dried peels were crushed into a fine powder and sieved using a 60-mesh (≈250

μm) sieve. Before being examined further, the resultant dietary fiber concentrates (DFCs) were placed in sealed food-grade containers and kept at room temperature.

Fig 1: Peel processed for Dietary Fiber Concentrate

2.3 Nutritional Analysis of Dietary Fibre Concentrates

2.3.1 Moisture Content

The oven-drying method outlined in AOAC Method 925.10 was used to determine the moisture content of the dietary fiber concentrates (DFCs) (AOAC, 2019). After precisely weighing each sample, around 5 g of it was put in a hot-air oven set at 105 °C. The drying process was carried out until a steady weight was achieved, signifying the total elimination of moisture. The proportion of the initial sample weight that was lost during drying was used to compute the moisture content.

2.3.2 Crude Fat Content

Using a Soxhlet extraction device, the crude fat content of the dietary fiber concentrates was measured in accordance with AOAC Method 920.39. After precisely weighing two to three grams of the material, it was continuously extracted with petroleum ether for six hours. The solvent was eliminated after extraction, and the leftover lipid residue was dried and weighed. The weight of the extracted residue was used to determine the crude fat content, which was then expressed as a percentage (%) of the sample.

2.3.3 Crude Protein Content

The Kjeldahl procedure, as described in AOAC Method 979.09, was used to quantify the samples' crude protein concentration. Acid digestion of the sample was the first step in the analysis, which was followed by distillation and titrimetric measurement of the nitrogen liberated. A nitrogen-to-protein conversion factor of 6.25 was used to convert the nitrogen content to protein. Based on sample weight, the final crude protein value was computed and expressed as a percentage (%).

2.3.4 Total Ash Content

The AOAC Method 923.03 was used to calculate the total ash content. After precisely weighing around 2 g of the sample into a crucible that had already been weighed, it was burned in a muffle furnace that was kept at 550°C. Heating was maintained until all of the organic materials had completely burned, leaving a homogenous, light gray residue. The ash residue was weighed after cooling in a desiccator, and the ash content was computed and reported as a percentage (%) of the initial sample weight.

2.3.5 Crude Fibre Content

The analysis of crude fiber content followed AOAC Method 962.09. To eliminate soluble components, the sample was successively digested with diluted acid and alkali solutions. To ascertain the amount of ash in the residual, it was then dried, weighed, and burned. Crude fiber was computed as a percentage (%) of the sample weight using the difference between residue weights before and after ash.

2.3.6 Carbohydrate Content

Total carbohydrate content was estimated by the difference method. The percentage of carbohydrates was obtained by subtracting the sum of moisture, crude protein, crude fat, total ash, and crude fibre contents from 100. The calculated value was expressed as a percentage (%) of the sample composition.

Carbohydrate (%) = 100 − [Moisture (%) + Protein (%) + Fat (%) + Ash (%) + Fibre (%)]

2.3.7 Total Phenolic Content

According to Singleton et al. (1999), the Folin-Ciocalteu test was used to determine the samples' total phenolic content. Folin-Ciocalteu reagent was combined with extracts made with 80% ethanol, and then sodium carbonate solution was added to aid in color development. A UV-Visible spectrophotometer was used to measure the reaction mixture's absorbance at 765 nm following incubation. A gallic acid calibration curve was used for quantification, and the findings were given in milligrams of gallic acid equivalents (mg GAE) per 100 grams of material.

2.4 Structural Characterization of Dietary Fibre Concentrates

2.4.1 Scanning Electron Microscopy (SEM)

The dietary fiber concentrates' microstructural characteristics were examined with a scanning electron microscope (JSM-7610F Plus, JEOL, Japan). To reduce charging effects during observation, samples were placed on conductive stubs and sputter-coated with gold in an argon environment. The surface appearance, structural configuration, and particle properties of the fiber concentrates were evaluated by taking micrographs at various magnifications.

2.4.2 X-ray Diffraction Analysis (XRD)

To determine if the dietary fiber concentrates were crystalline, X-ray diffraction analysis was used. Diffractograms were captured with a step size of 0.05° and a scan rate of 0.21° s^{-1} throughout a diffraction angle (2θ) range of 5° to 50°. The crystallinity and molecular organization of the fiber-rich samples were next assessed using the acquired XRD profiles.

2.4.3 Fourier Transform Infrared Spectroscopy (FTIR)

Fourier Transform Infrared (FTIR) spectroscopy was used to investigate the chemical composition and functional groups of the dietary fiber concentrates. For spectrum investigation, a Shimadzu FTIR spectrometer was utilized. 16 scans were recorded for each measurement, and about 10 mg of finely powdered material was assessed across the 400–4000 cm^{-1} spectral range in order to get high-quality spectra. Distinctive absorption bands in the collected spectra were used to identify the main structural polysaccharides and bioactive components. Particular focus was placed on absorption peaks associated with cellulose, hemicellulose, lignin, and other functional components, which provided information about the molecular composition and chemical structure of the dietary fiber concentrates.

2.4.4 Energy Dispersive X-ray Spectroscopy (EDS)

An Energy Dispersive X-ray Spectroscopy (EDS) detector combined with the Scanning Electron Microscopy (SEM) equipment was used to determine the elemental composition of the dietary fiber concentrates. To guarantee precise elements detection, measurements were performed under suitable vacuum and accelerating voltage conditions. The elemental components found in the samples were identified and measured using the EDS spectra that were produced. The spectrum data was used to calculate the relative abundance of key elements, such as carbon (C), oxygen (O), potassium (K), calcium (Ca), magnesium (Mg), and other trace minerals. Important details about the elemental distribution and mineral content of the dietary fiber concentrates were revealed by this study.

3. Results

3.1 Proximate Composition Analysis of Dietary Fibre Concentrates

The proximate analysis revealed that both mango and potato peel fibre concentrates are rich in dietary fibre, making them suitable for functional food applications. Mango peel concentrate exhibited comparatively higher dietary fibre and ash content, indicating a higher mineral presence and potential health benefits. In contrast, potato peel concentrate showed relatively higher carbohydrate content, suggesting its utility as an energy-contributing ingredient.

The low moisture content in both samples indicates good shelf stability, while the moderate protein and fat levels contribute to their nutritional value. These findings are consistent with previous studies highlighting the nutritional richness of fruit and vegetable by-products.

The proximate composition demonstrated statistically significant differences ($p < 0.05$) between mango and potato peel fibre concentrates. Mango peel exhibited significantly higher protein content (6.20%) compared to potato peel (3.56%), indicating its superior nutritional value for protein enrichment in functional foods.

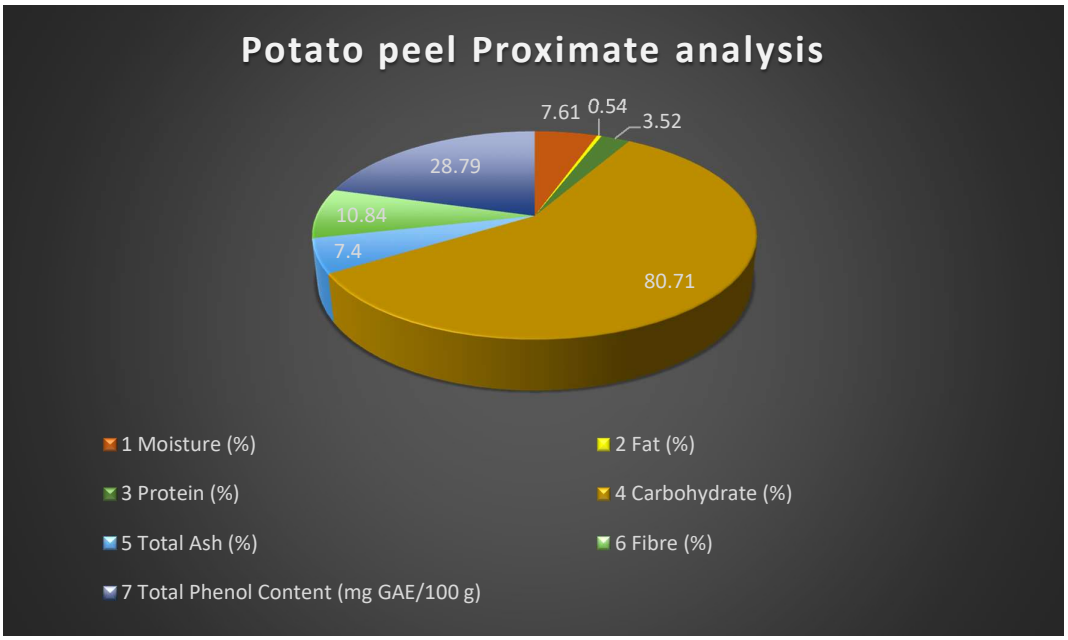
Crude fibre content was markedly higher in mango peel (7.32%) than potato peel (1.90%), confirming its enhanced potential as a dietary fibre source. This higher fibre fraction is associated with improved physiological benefits such as enhanced gut health and glycaemic control.

In contrast, potato peel showed significantly higher ash content (7.44%), suggesting a richer mineral composition. Carbohydrate content was high in both samples, with mango peel slightly higher (82.76%), indicating its potential as an energy source.

Notably, total phenolic content was significantly higher in mango peel (50.95 mg GAE/100 g) than potato peel (28.87 mg GAE/100 g), suggesting stronger antioxidant potential. This highlights mango peel as a promising ingredient for antioxidant-enriched functional foods.

Table 2: Proximate Composition and Total Phenolic Content of Mango and Potato Peel Powder (Mean ± SD, n = 3)

S. No.	Parameter	Potato Peel	Mango Peel
1	Moisture (%)	7.66	8.41
2	Fat (%)	0.56	1.23
3	Protein (%)	3.56	6.20
4	Carbohydrate (%)	80.78	82.77
5	Total Ash (%)	7.44	1.39
6	Fibre (%)	10.90	12.32
7	Total Phenols (mg GAE/100g)	28.87	50.95



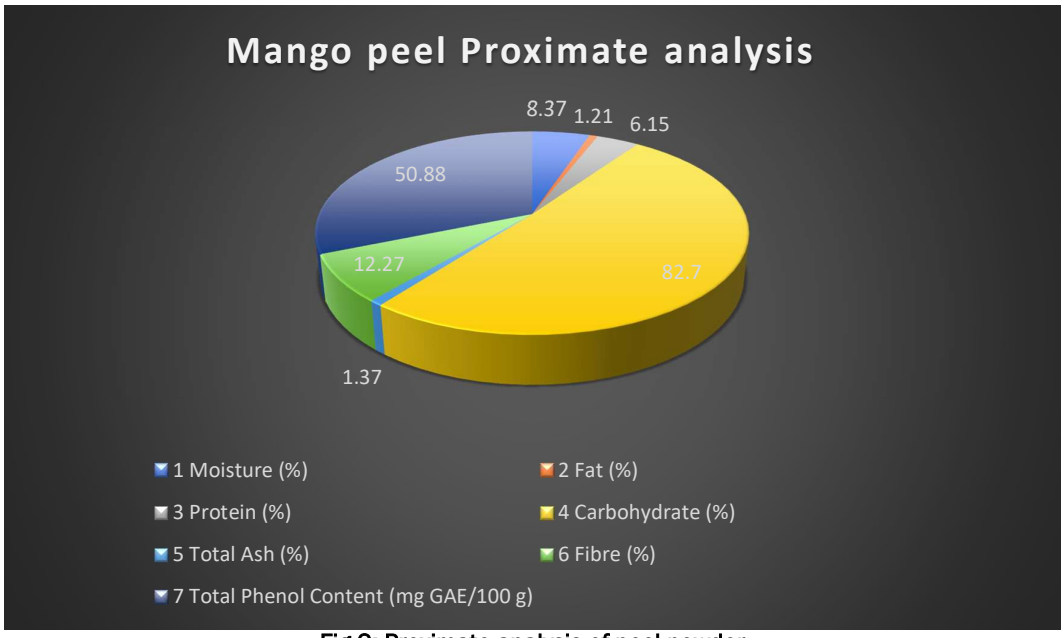


Fig 2: Proximate analysis of peel powder

3.2 Structural Analysis of Dietary Fibre Concentrates

The structural and morphological characteristics of dietary fibre concentrates obtained from mango (*Mangifera indica* L.) and potato (*Solanum tuberosum* L.) peels were evaluated using advanced analytical techniques, including scanning electron microscopy (SEM), Fourier-transform infrared spectroscopy (FTIR), and X-ray diffraction (XRD).

3.2.1 Scanning Electron Microscopy (SEM)

An SEM (JEOL JSM-series, Japan) was used to examine the surface morphology and microstructural features of the fiber powders. To enhance electrical conductivity and picture clarity, the samples were mounted on aluminum specimen stubs using double-sided conductive adhesive tape and vacuum-sputter-coated with a small coating of gold before analysis. In order to assess morphological characteristics such as surface texture, porosity, roughness, particle shape, and size distribution, micrographs were taken at different magnifications (500×, 1000×, and 2000×). SEM analysis made it possible to evaluate the fiber powders' structural properties in great detail and offered important details on the physical alterations brought about by the drying and milling procedures.

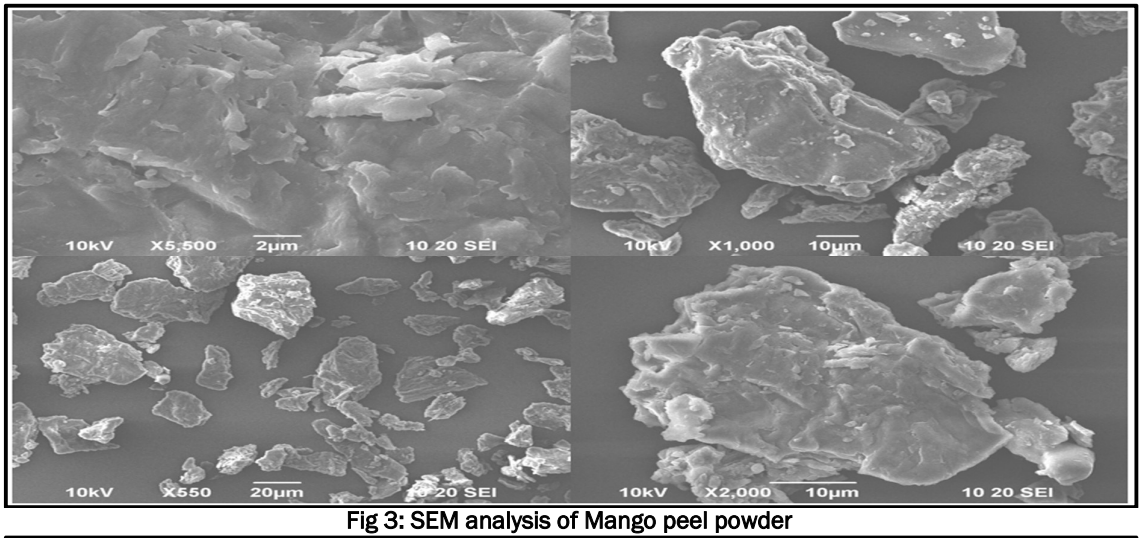


Fig 3: SEM analysis of Mango peel powder

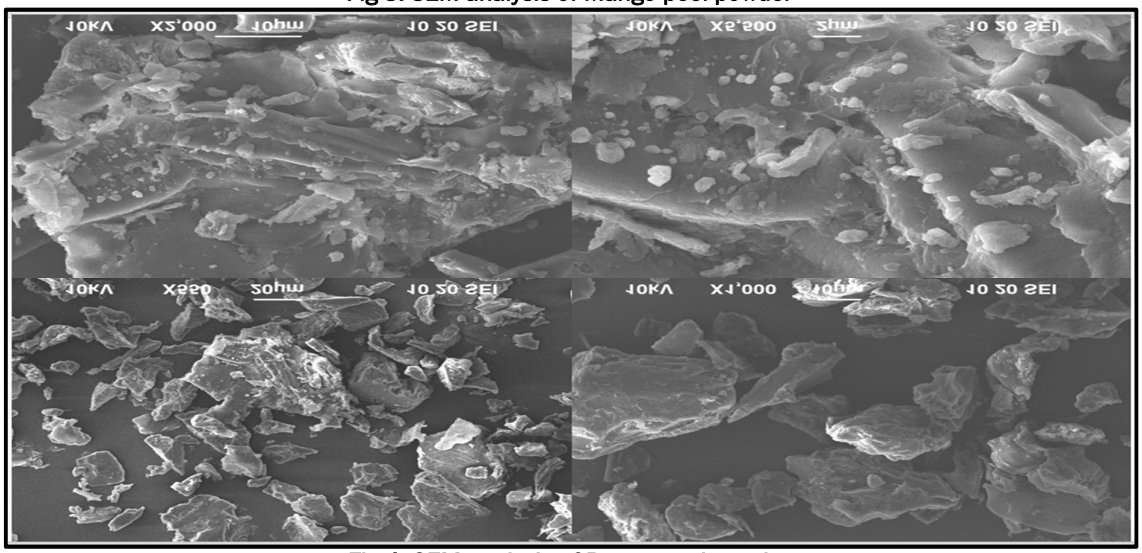


Fig 4: SEM analysis of Potato peel powder

3.2.2 SEM-Based Interpretation

The scanning electron micrographs revealed distinct structural differences between mango and potato peel dietary fibre concentrates. Mango peel powder exhibited a highly irregular, porous, and fibrous with fragmented particles, indicating significant structural disruption during drying **(Fig. 3)**. In contrast, potato peel powder showed comparatively smoother, more compact, and aggregated with limited porosity **(Fig. 4).** The higher porosity and loose structural observed in mango peel powder suggest a larger surface area, which is directly associated with enhanced **water holding capacity (WHC)** and **swelling behaviour.** The presence of well-developed fibrous further supports its superior dietary fibre functionality. On the other hand, the compact and dense structure of potato peel powder may restrict water penetration and limit swelling capacity. However, it may contribute to better **oil holding capacity (OHC)** due to tighter particle packing and reduced.

Overall, the SEM analysis confirms that mango peel powder possesses a more desirable for functional food applications, particularly in fibre enrichment, hydration properties, and antioxidant delivery, whereas potato peel powder exhibits comparatively lower functional efficiency due to its compact morphology.

3.3 Energy Dispersive X-ray Spectroscopy EDS Analysis

The organic character of the fiber-rich materials was confirmed by the EDS analysis, which showed that carbon (C) and oxygen (O) made up the majority of the powders from potato and mango peels. However, the elemental makeup of the two samples differed noticeably. The oxygen content of mango peel powder was much higher (47.79 weight percent), indicating a larger concentration of oxygen-containing functional groups, such as hydroxyl and carboxyl moieties. The physicochemical and functional characteristics of dietary fiber materials are influenced by structural polysaccharides such as cellulose, hemicellulose, and pectin, which are frequently linked to these functional groups. Additionally, the presence of **calcium (Ca)** suggests structural reinforcement of plant cell walls, supporting SEM observations of a fibrous and porous morphology. In contrast, potato peel showed **higher carbon content (56.24 wt%)**, reflecting a **greater proportion of starch and polysaccharides.** The significantly higher levels of **potassium (K) and chlorine (Cl)** in potato peel indicate a richer mineral composition, which is consistent with its known nutritional profile. The presence of **sulfur (S)** further suggests minor protein or sulfur-containing compounds.

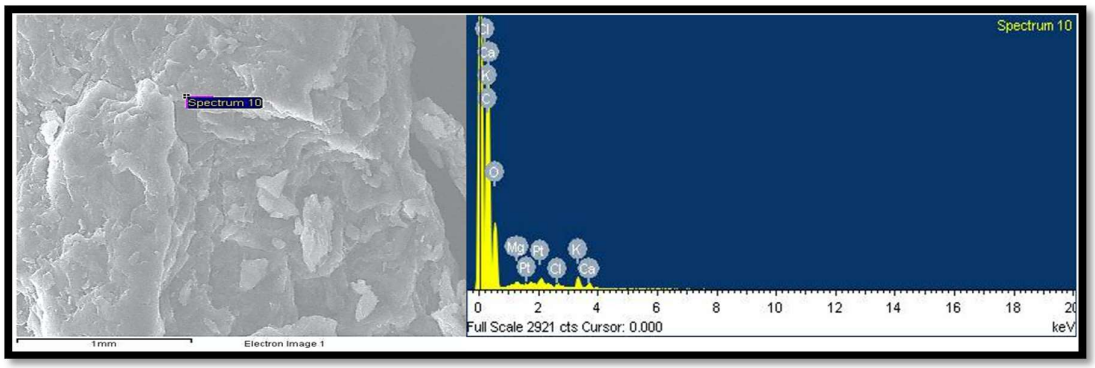


Fig 5: Mango peel EDS

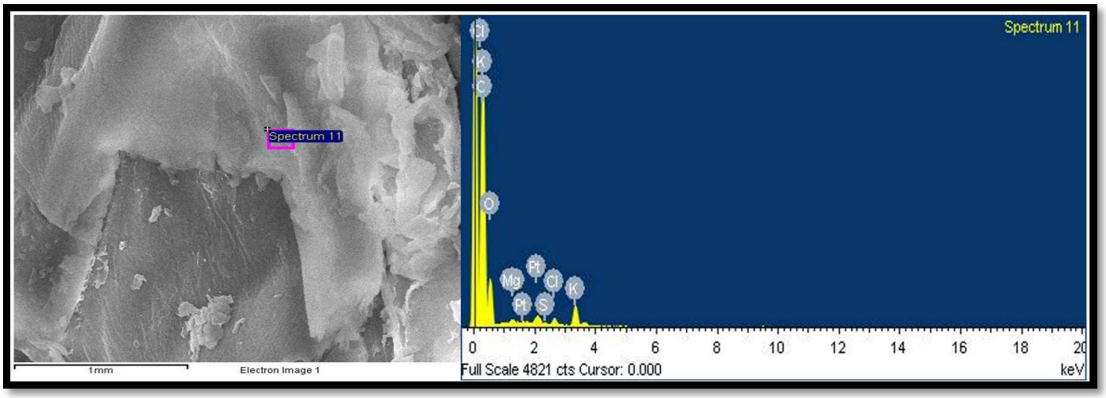


Fig 6: potato peel EDS

The **absence of calcium in potato peel** and its presence in mango peel highlights compositional variation linked to plant physiology. Furthermore, the relatively lower oxygen content in potato peel supports its **more compact and less porous SEM structure,** as fewer oxygenated functional groups reduce surface reactivity. The platinum (Pt) detected in both samples is attributed to **sample coating during SEM preparation** and does not contribute to the intrinsic composition.

Table 4: Comparative EDS Results of Mango and Potato Peel Powder

Element	Mango Peel (Wt%)	Mango Peel (At%)	Potato Peel (Wt%)	Potato Peel (At%)	Interpretation
C (Carbon)	47.82	56.45	56.24	65.32	Higher in potato peel → indicates higher organic/starch content
O (Oxygen)	47.79	42.35	37.88	33.03	Higher in mango peel → reflects oxygenated functional groups (fiber, cellulose)
Mg (Magnesium)	0.38	0.22	0.34	0.20	Similar trace mineral in both samples
S (Sulfur)	—	—	0.19	0.08	Present only in potato peel → minor protein/mineral contribution
Cl (Chlorine)	0.35	0.14	0.73	0.29	Higher in potato peel → mineral salt content
K (Potassium)	1.47	0.53	2.67	0.95	Significantly higher in potato peel → nutrient-rich mineral profile
Ca (Calcium)	0.53	0.19	—	—	Present only in mango peel → structural role in cell walls
Pt (Platinum)	1.67	0.12	1.96	0.14	Due to coating during SEM preparation (not intrinsic)
Total	100	100	100	100	—

Note: Mango peel powder exhibits higher oxygen and the presence of calcium, indicating a fibre-rich structure with better adsorption capacity and structural stability. In contrast, potato peel powder shows higher carbon and potassium content, reflecting greater starch and mineral composition, suitable for thickening and food formulation. Trace elements vary between samples, while platinum (Pt) is attributed to SEM coating and not intrinsic to the materials.

3.4 Spectrum of Fourier-Transform Infrared Spectroscopy (FTIR)

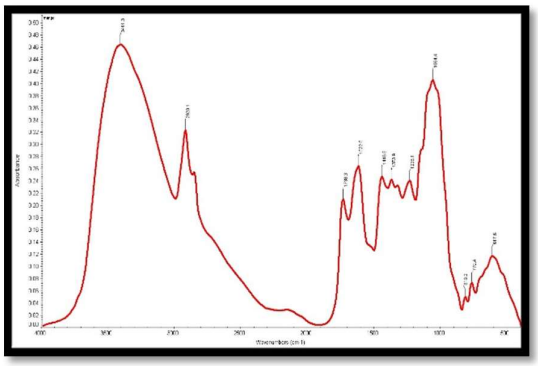


Fig 7: Mango peel FTIR

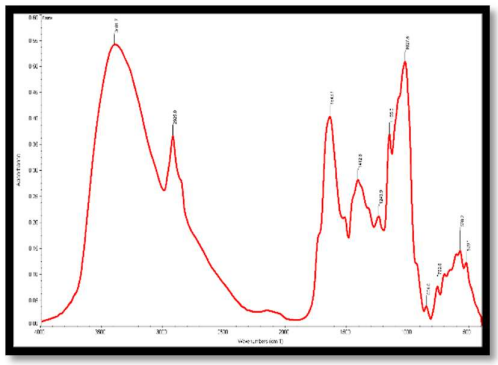


Fig 8: Potato peel FTIR

Table 5: Comparative FTIR Analysis of Mango and Potato Peel Dietary Fibre Concentrates

Wavenumber (cm^{-1})	Functional Group Assignment	Mango Peel Powder (Observation)	Potato Peel Powder (Observation)	Comparative Interpretation
~3400-3410	O-H stretching (hydroxyl groups, hydrogen bonding)	Broad and intense peak at ~3411 cm^{-1} indicating strong hydrogen bonding and high fibre-associated hydroxyl groups	Broad peak at ~3401 cm^{-1} with slightly lower intensity	Mango peel shows stronger hydrogen bonding → higher lignocellulosic fibre content

~2920-2930	C-H stretching (aliphatic chains)	Moderate peak at ~2923 cm^{-1} indicating presence of polysaccharides and minor lipids	Similar peak at ~2925 cm^{-1}	Both samples contain comparable aliphatic components
~1730	C=O stretching (ester groups, pectin)	Weak but noticeable peak indicating presence of pectin and hemicellulose	Very weak or absent peak	Mango peel contains higher pectin and esterified compounds
~1600-1650	Bound water / aromatic lignin (C=C stretching)	Moderate peak at ~1622 cm^{-1}	Stronger peak at ~1643 cm^{-1}	Higher intensity in potato peel indicates greater water association or amorphous structure
~1400-1450	CH□ bending / lignin	Peak at ~1446 cm^{-1}	Peak at ~1412 cm^{-1}	Mango peel shows slightly higher lignin-related structure
~1360-1380	C-H bending	Peak at ~1373 cm^{-1}	Peak at ~1365 cm^{-1}	Similar structural characteristics in both samples
~1240-1260	C-O stretching (hemicellulose/lignin)	Peak at ~1249 cm^{-1}	Peak at ~1243 cm^{-1}	Slightly stronger in mango peel indicating more hemicellulose content
~1000-1100	C-O and C-O-C (cellulose, polysaccharides, starch)	Strong peak at ~1064 cm^{-1} indicating cellulose-rich structure	Very strong and sharp peak at ~1027 cm^{-1} indicating starch dominance	Mango peel → fibre-rich; Potato peel → starch-rich composition
~900-950	β-glycosidic linkages (cellulose structure)	Present with moderate intensity	Present with moderate intensity	Confirms presence of polysaccharide backbone in both
~500-700	Skeletal vibrations (fingerprint region)	Peaks at ~517–700 cm^{-1}	Peaks at ~528–760 cm^{-1}	Minor structural variations between samples

3.5 Analysis of X-ray Diffraction (XRD)

Mango peel powder's X-ray diffraction profile showed a wide diffraction pattern with several peaks in the low-angle region (5°–10°), indicating that amorphous components predominated in the matrix. The primary causes of these amorphous areas are lignin fractions and non-crystalline polysaccharides that are frequently found in biomass generated from plants. Cellulose I was characterized by prominent diffraction peaks with 2θ values of around 20.3° and 20.9°, which showed the presence of organized crystalline cellulose domains. The coexistence of crystalline and amorphous areas illustrates the material's semi-crystalline architecture, with amorphous elements making up the majority. These structural traits, which are typical of lignocellulosic residues, may facilitate the use of mango peel powder as a sustainable source of dietary fiber in food applications by contributing to its desired functional and physicochemical qualities.

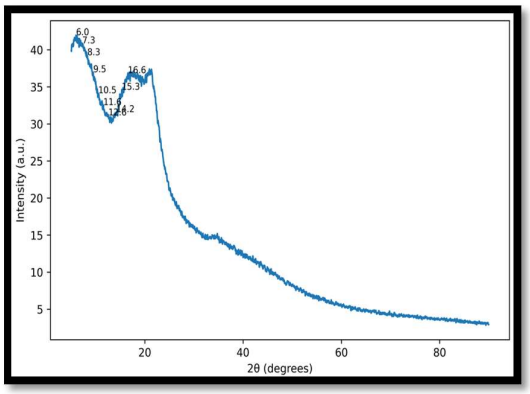


Fig 9: Mango peel XRD

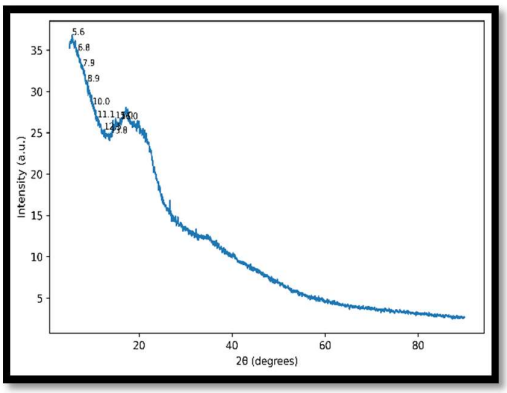


Fig 10: Potato peel XRD

Mango peel powder's XRD pattern showed a distinctive peak close to 2θ = 22°, which corresponded to cellulose I's crystalline areas. The presence of amorphous components, namely hemicellulose and lignin, was suggested by the wide diffuse backdrop. These results support the material's semi-crystalline structure and prevalence of amorphous components, which are characteristic of sources of lignocellulosic dietary fiber.

Potato peel powder's XRD diffractogram showed noticeable peaks in the low-angle area (5°–10°), indicating a sizable amorphous fraction mostly made up of starch and other polysaccharides. Semi-crystalline B-type starch, a structural property frequently seen in potato-based products, was detected by a distinctive peak at 2θ = 17.25°.

3.6 Dietary Fibre Content and Functional Implications

The samples' high dietary fiber content indicates their potential as functional food ingredients with potential advantages for managing the risk of chronic diseases and digestive health. In addition to supporting gastrointestinal health, dietary fiber may help food systems retain more water, stay hydrated, and have better viscosity.

4. Discussion

The present investigation demonstrated that dietary fibre concentrates derived from fruit and vegetable processing residues possess valuable nutritional and structural characteristics that support their application as functional food ingredients. The high dietary fibre, carbohydrate, mineral, and phenolic contents observed in the concentrates highlight the nutritional potential of agro-industrial by-products, which have increasingly

been recognized as sustainable sources of value-added food ingredients (Ospina-Maldonado et al., 2024). The low moisture content recorded in the samples is advantageous for storage stability, as reduced water availability limits microbial growth and minimizes deterioration during storage (Singh et al., 2023). The substantial dietary fibre content confirms the effectiveness of the processing approach in concentrating structural polysaccharides from plant tissues. Dietary fibre has been widely associated with improved gastrointestinal health, modulation of glycaemic response, cholesterol reduction, and overall metabolic well-being (Chhikara et al., 2020). Beyond its physiological benefits, dietary fibre contributes significantly to the technological performance of food systems through its hydration, thickening, and texture-modifying properties (Fayaz & Galasso, 2024). The retention of carbohydrate-rich polysaccharides further supports the potential use of these concentrates as functional ingredients in food formulations (Lesmana et al., 2021).

The presence of measurable phenolic compounds indicates that the fibre concentrates retained bioactive constituents naturally present in plant tissues. Phenolic compounds are recognized for their antioxidant activity and their ability to scavenge reactive oxygen species, thereby contributing to health-promoting effects (Riar & Panesar, 2024). The association of phenolic compounds with dietary fibre matrices has been reported to enhance the functional value of plant-derived ingredients, resulting in the concept of antioxidant dietary fibre, which combines physiological and antioxidant benefits within a single ingredient (K. Abdulrahman, 2025).

Microstructural analysis by scanning electron microscopy revealed irregular particle morphology, fibrous structures, and porous surface features, which are characteristic of lignocellulosic biomass materials (Kapoor et al., 2025). Microstructural analysis revealed irregular particle morphology, fibrous structures, and porous surface characteristics, which are typical features of plant-derived lignocellulosic materials. Such morphological characteristics are known to increase the available surface area and facilitate interactions with water and lipids, thereby enhancing hydration behaviour, swelling capacity, and adsorption properties. Moreover, structural modifications induced by drying and milling processes may expose additional fibre surfaces, improving the accessibility and techno-functional performance of dietary fibre ingredients in food systems (Tejada-Ortigoza et al., 2021). The elemental composition obtained through EDS analysis further confirmed the organic nature of the dietary fibre concentrates. The predominance of carbon and oxygen is characteristic of lignocellulosic biomass and reflects the abundance of structural polysaccharides, including cellulose, hemicellulose, and pectin, within the plant cell wall matrix (Synytsya & Novak, 2014). Furthermore, the detection of mineral elements such as potassium, calcium, and magnesium indicate that peel-derived fibre concentrates may serve as supplementary sources of nutritionally important micronutrients in addition to dietary fibre.

The FTIR spectra provided additional evidence regarding the complex chemical composition of the fibre concentrates. Characteristic absorption bands associated with hydroxyl, carbonyl, and polysaccharide functional groups confirmed the presence of cellulose, hemicellulose, lignin, and pectin, which are major structural constituents of plant-based dietary fibres (Kacuráková, 2000). The broad hydroxyl stretching bands observed in the spectra indicate extensive intermolecular hydrogen bonding within the fibre matrix, a feature that significantly influences water-binding capacity and overall functional behaviour (Synytsya & Novak, 2014). These functional groups play an important role in determining the physicochemical and technological properties of dietary fibres during food processing and storage.

The X-ray diffraction patterns revealed the coexistence of crystalline and amorphous regions, confirming the semi-crystalline nature of the dietary fibre concentrates. The diffraction peaks associated with cellulose crystallites indicate the presence of ordered structural domains, whereas the broad amorphous background reflects contributions from hemicellulose, lignin, pectin, and other non-crystalline constituents commonly found in lignocellulosic biomass **(Park et al., 2009)**. Such structural organization has important implications for ingredient functionality, as amorphous regions generally promote water absorption, swelling behaviour, and fermentability, while crystalline domains contribute to structural stability and mechanical integrity. The balance between these structural fractions may therefore influence the hydration characteristics, processing behaviour, and functional performance of dietary fibre concentrates in food applications.

Overall, the nutritional composition and structural characteristics identified in this study demonstrate the considerable potential of peel-derived dietary fibre concentrates as sustainable functional food ingredients. The combined presence of dietary fibre, bioactive compounds, essential minerals, and favourable structural attributes supports their utilization in fibre enrichment, clean-label product development, and agro-industrial waste valorization strategies **(Galanakis, 2012)**. These findings further reinforce the importance of transforming fruit and vegetable processing residues into value-added ingredients, thereby contributing to resource efficiency, environmental sustainability, and the advancement of circular bioeconomy systems **(Kilemile et al., 2025).**

5. Conclusion

The present study demonstrates that mango and potato peels are valuable sources of dietary fibre concentrates with significant nutritional and structural properties. Mango peel fibre exhibited higher dietary fibre and mineral content, while potato peel fibre showed higher carbohydrate levels. Structural analyses confirmed the presence of functional groups and morphological characteristics suitable for food applications. These findings highlight the potential of utilizing agro-waste for developing functional food ingredients, contributing to both sustainability and improved nutrition. Future research can focus on the incorporation of these dietary fibre concentrates into various food products such as bakery and extruded items to evaluate their functional performance and sensory acceptability. Additionally, in-depth studies on antioxidant activity, bioavailability, and shelf-life stability can further enhance their application in nutraceutical and functional food industries. Scale-up studies and industrial applications may also be explored to promote sustainable waste utilization. The novelty of the present study lies in the comparative physicochemical and functional characterization of mango peel powder, potato peel dietary fiber concentrate, and foxtail millet flour within a single analytical framework. Prior studies have mostly examined single fruit or vegetable by-products, but thorough analyses of several agro-industrial leftovers are still hard to come across. To ascertain if dietary fiber fractions are suitable as functional food ingredients, this study offers an integrated evaluation of their structural features, functional qualities, and fractions. In addition to supporting waste reduction initiatives, the obtained compositional and functional data help to value processing by-products as nutrient-rich, sustainable ingredients for food applications.

Declarations

Ethics Approval and Consent to Participate

This study did not include human participants, human data, or animal subjects. As a result, ethics approval and informed consent were not necessary.

Consent for Publication

Not applicable.

Availability of Data and Materials

All data generated or analysed during this study are included within the manuscript. Additional datasets supporting the conclusions of this study are available from the corresponding author upon reasonable request.

Competing Interests

The authors declare that they have no competing financial or non-financial interests.

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Authors' Contributions

Shailesh Kumar conceptualized the study, conducted experimental work, data analysis, and manuscript drafting. Prof. Sunita Mishra, Dr. Priyanka Shankar contributed to data interpretation, critical review, and manuscript refinement. All authors read and approved the final manuscript.

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